APPLICATION FOR UNITED STATES PATENT

METHOD AND APPARATUS FOR FORMING AN UNDERFILL ADHESIVE LAYER

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CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation-in-part of co-pending application serial number 09/359,214, filed July 22nd, 1999, which is incorporated herein by reference. This application is also related to U.S. patent No. 6,245,595 which is also incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The present invention relates generally to a wafer level packaging process for integrated circuits. More particularly, the invention relates to various packaging arrangements wherein an underfill material is applied to a wafer prior to dicing.

BACKGROUND OF THE INVENTION

[0003] There are a number of conventional processes for packaging integrated circuits. One approach which is commonly referred to as "flip chip" packaging generally contemplates forming solder bumps (or other suitable contacts) directly on an integrated circuit die. The die is then "flipped" and attached to a substrate such as a printed circuit board or substrate. That is, the solder bumps on the die are aligned and mounted onto matching contacts on the substrate. The solder bumps are then reflowed to electrically connect the die to the substrate.

[0004] When a flip chip die is mounted to the substrate, an air gap typically remains between the die and substrate. This gap is commonly filled with material that is flowed into the gap in liquid form and is then solidified. This material is generally a mixture of a epoxy resin and small silica spheres and is often called underfill. The underfill material is typically applied in liquid form from a dispenser at one edge of the die. The material then

flows into the narrow gap due to capillary action and spreads across the flip chip die until finally the entire area of the gap between the die and substrate is filled.

[0005] There are problems associated with this type of underfill process. For example, the operation of applying underfill must be repeated for each flip chip mounted onto a substrate. Repeating such an operation many times during manufacturing significantly increases costs. Also, as the underfill material flows past solder bumps to fill the gap, separation of silica spheres from resin may occur. The separation of silica spheres from the resin occurs as some silica spheres become trapped as they meet solder ball obstacles. The underfill material may therefore develop streaks of high and low silica concentration. The silica may also separate from the resin by sinking to one side of the gap, thus creating a silica rich side in the bottom and a resin rich side on the top of the gap. This segregation of silica and resin alters the mechanical properties of the filled region and thereby may mitigate the mechanical function of the underfill.

[0006] Although the described process works well, there is always a desire to provide more cost effective processes for packaging integrated circuits.

SUMMARY OF THE INVENTION

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[0007] To achieve the foregoing and other objects and in accordance with the purpose of the present invention, an apparatus and method for forming a layer of underfill adhesive on an integrated circuit in wafer form is disclosed. In one embodiment, the layer of underfill adhesive is disposed and partially cured on the active surface of the wafer. Once the underfill adhesive has cured, the wafer is signulated. The individual integrated circuits or die are then mounted onto a substrate such as a printed circuit board. When the solder balls of the integrated circuit are reflowed to form joints with corresponding contact pads on the substrate, the underfill adhesive is completely cured. In an alternative embodiment, the underfill adhesive is fully cured after it is disposed onto the active surface of the wafer. In various other embodiments, the underflow adhesive is disposed onto the wafer using stencil printing, screen printing, molding, or a spin on deposition process. The underflow adhesive is selected from a group of materials including, but not limited to, epoxies, poly-imides, or silicone-polyimides copolymers and includes one or more of the following components: epoxy resin, a hardener, a catalyst initiator, a coloring dye and an inorganic filler.

BRIEF DESCRIPTION OF THE DRAWINGS

The features of the present invention may best be understood by reference to the following description of the presently preferred embodiments together with the accompanying drawings. For the sake of clarity the drawings are not to scale.

Figure 1(a) is a wafer with surface mount semiconductor dice fabricated thereon.

Figure 1(b) is a surface mount semiconductor die scribed from the wafer of Figure 1(a).

Figures 2(a) through 2(c) are a series of cross-section figures illustrating how solder balls are formed on the active surface of the die of Figure 1(b) respectively.

Figures 3(a) and 3(b) illustrate partial cross sections of the wafer of Figure 1(a) having a pre-cured and a post cured underfill layer according to one embodiment of the invention.

Figure 4 illustrates a flip chip of the present invention mounted to a substrate such as a printed circuit board.

Figure 5(a) and Figure 5(b) is a top view and a cross section view of a wafer according to another embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0008] Referring to Figure 1(a), a wafer with surface mount semiconductor dice fabricated thereon is illustrated. The wafer 100 includes a plurality of surface mount dice 102 (hereafter "die" or "dice") separated by horizontal and vertical scribe lines 104. Each of the die 102 include a plurality of solder contact balls 106 which are intended to be mounted directly onto contact pads of a substrate such as a printed circuit board. It should be noted that for clarity, only a relatively small number of dice 102 are shown on the wafer 100. In actuality, most wafers will have significantly more dice formed thereon. By way of example, current state of the art wafers typically have several hundred to several thousand dice formed thereon and some have more than ten thousand dice. As is well known in the art, most wafers are formed of silicon but they can, of course, be formed of any other appropriate semiconductor material including, for example, gallium arsenide (GaAs).

[0009] Referring to Figure 1(b), an individual die 102 scribed from the wafer of Figure 1(a) is shown. After the wafer 100 is fabricated and contact balls 106 are formed thereon, a dicing machine is used to singulate the individual die 102 by sawing the wafer 100 along the scribe lines 104.

[0010] Referring to Figures 2(a) through 2(c), a series of partial cross-section figures of the wafer 100 illustrating how solder balls 106 are formed on the active surface of a die 102 is respectively shown. It should be noted that in the following description, numerous specific details are set forth in order to provide a thorough understanding of the present invention. In view of this description, however, it will be obvious to those skilled in the art that the present invention may be embodied in a wide variety of specific

configurations. Also, in order not to unnecessarily obscure the present invention, well-known integrated circuit manufacturing steps are not described herein in detail.

[0011] In the initial step as illustrated in Figure 2(a), a number of underbump metallization pads 110 are formed on the surface of the die 102. The underbump metallization pads 110 may be formed by a number of conventional processes. For example, a layer of solder or other conductive metal is applied on the surface of the die 102. The surface is then masked and etched, leaving the pads 110. In the next step as illustrated in Figure 2(b), solder paste islands 112 are formed on the pads 110. After the solder paste islands 112 are in place, corresponding solder balls 106 are formed by heating the wafer 100 causing the solder to reflow forming the solder balls 106. The resulting structure is illustrated in Figure 2(c). It is useful to note that the "bowl-like" shape underbump metallization pad 110 provides a barrier to the lateral flow of the solder paste during the reflow operation. The underbump metallization pad 110 also provides a barrier metal between the solder ball 106 and the interconnects within flip chip die 102.

[0012] In various embodiments of the invention, an underfill layer is applied to the wafer 100 before the wafer is diced. The underfill may be applied in a variety of different manners including, for example, stencil printing, screen printing, molding or spin coating. In many embodiments, a B-stageable adhesive material (such as a B-stageable epoxy) is used to form the underfill material. Typically, the wafer 100 will have solder balls 106 formed on the pads 110 before the underfill material is applied. When a B-stageable underfill adhesive material is used, the underfill material is either partially or fully cured after being applied. In either state, the wafer 100 can be readily handled and diced thereby singulating the individual die 102. The resulting dice 102 can then be secured to any suitable substrate (such as printed circuit boards, package substrates, etc.) using conventional solder reflow techniques. In situations where the underfill material is only

partially cured, the properties of the underfill adhesive may be chosen so that the reflowing of the solder contacts during mounting finally cures the underfill adhesive. In other embodiments of the invention, a B-stageable underfill adhesive can be applied to the active surface of the wafer and then fully cured.

[0013] More specifically, after the solder balls 106 have been formed, a layer of underfill is applied across the wafer 100. As noted, the underfill adhesive may be applied using a wide variety of techniques including stencil printing, screen printing, molding or spin-on processes. Each technique for applying underfill has advantages and disadvantages. By way example, molding works well and uses readily available equipment. As described in the previously referenced patent No. 6,245,595, the balls 106 are typically (although not always) flattened in the molding operation which can be an advantage or a disadvantage depending on the application. Screen printing allows the application of variable thickness coatings using inexpensive tooling screens. Typically, when screen printing is used, a relatively low to medium solvent-based resin formulation may be used as the underfill material. Stencil printing tends to provide better height control than screen printing, although the stencils tend to be more expensive than screens. As is well known to those familiar with the art, stencils used in conventional stencil printing operations typically have a relatively large opening in a relatively rigid sheet of material such as metal. The opening(s) is/are shaped to match that of the area(s) being printed. Otherwise, stencil printing is quite similar to screen printing. Typically underfill material with somewhat higher solvent percentages are used during stencil printing than screen printing.

[0014] In one embodiment of the invention, the applicants recommend using an underfill material having the following properties: viscosity: 2,000 to 10,000 mPa.s (milli Pascal.second); specific gravity: 1.0 to 1.2; solvent content: 20 to 45% (by weight); B-

stage cure time of 20 to 30 minutes at 100 to 130 degrees C under vacuum; and filler content: 1-10% (by weight). Solvent is added mainly to control the viscosity of the formulation, which includes epoxy resin, hardener, initiators (catalysts), dye (for color), and inorganic fillers. Key desirable properties of the underfill are: high glass transition temperature (Tg), low coefficient of thermal expansion (CTE), and good adhesion. High Tg material allows the underfill material to go through high temperature reflow with low risk of coating damage. High Tg materials are also obtainable through high molecular weight resins. Low CTE property is obtained through high filler loading. A preferred loading concentration aims to produce materials with CTEs between that of silicon (3x10-6 ppm/C) and the substrate (15x10-6 ppm/C) the die will be mounted on. Both options (high Tg and low CTE) tend to raise the viscosity of the formulation, and can be controlled by adding solvent.

[0015] By way of example, an underfill material having a coefficient of thermal expansion in the range of approximately 20 x 10^{-6}/K to approximately 30 x 10^{-6}/K @ 25 ^{0}C, typically works well in order to reduce thermally induced stress. The coefficient of thermal expansion value of typical solders is also in this range. Close agreement between the CTE values of these materials minimizes the generation of shear stresses between the underfill and the solder joints. One advantage to reducing thermal stress is that the overall reliability of the electrical connection formed by the solder joint is greatly enhanced.

[0016] In one specific embodiment, a reflow material having a solvent content of 40% is used. The observed advantages of using this percentage include: a lower viscosity so that flow coverage over the solder bumps and wafer passivation is enhanced; lower potential for air entrapment during coating; a lower incidence of microscopic voiding

trapped at the base of the solder bumps; and an optimized B-stage curing profile. Too much solvent does not allow for proper flow.

[0017] With the use of an underfill material with the above-defined characteristics, the applicants have found much of the solvent tends to evaporate during the curing process. Thus, the initial thickness of the underfill layer applied to the active surface of the wafer 100 needs to take into account the reduction in thickness due to solvent loss. In this example, the applicants have found that in order to produce a layer of underfill having a thickness that has a height substantially the same as the solder balls 106, the pre-curing thickness of the material needs to be approximately 140% of the height of the solder balls 106. In various other embodiments of the invention, an underfill material with a lower solvent content may be used. With the solvent content lower, the amount of solvent loss will be less. Therefore, the height of the pre-cured underfill layer needs to be selected so that the final cure height is at the desired level, typically at a height such that at least the top surface of the solder balls 106 are exposed.

[0018] The applicants have observed that a pre-curing underfill layer having a thickness of 90 to 140 percent of the height of solder balls 106 provided a preferred underfill coverage after curing and the die 102 is mounted onto a printed circuit board. Generally though, the thicker the layer, the better the filleting around the die, which in turn provides improved thermal cycling performance.

[0019] Referring to Figure 3(a) and 3(b), partial cross sections with underfill material provided across the active surface of the wafer 100 are shown. In Figure 3(a), the precured underfill material 130 has a height of 140% of the solder balls 106. In Figure 3(b), the height of the underfill material 130 after pre-curing exposes at least the top surface of the solder balls 106. It should be noted however, that this embodiment in no way should limit the score of the invention. The pre-cure and post-cure height can be

either higher or lower than those illustrated in these figures according to various embodiments of the invention.

[0020] In one embodiment of the invention, the underfill layer 130 is formed of a silica filled polymer resin having dual stage curing chemistry with specific, uncured, pre-cured, and fully cured properties. Examples of such a resin include: epoxy based, poly-imide based, or silicone-polyimide based materials.

[0021] In yet another embodiment, the layer of underfill adhesive is substantially opaque to protect the integrated circuitry on the die 102 from photo induced leakage currents by blocking visible light. The percentage of filler and the amount of dye included in the underfill adhesive 130 can be modified to control the opaqueness of the material.

[0022] As discussed above, in the currently described embodiment, the underfill material is formed from a B-stageable adhesive. The B-stage underfill may be tailored to meet the needs of the particular application. By way of example in one described embodiment, the B-stage underfill is tailored so that it starts melting at around 130°C and begins reacting after 183°C (the melting temperature of eutectic Tin-Lead solder). The underfill is designed so that is reaches about 90%+ cure by the time that the die cool down from would typically a second solder ball reflow. In this embodiment, the 90% cure is considered acceptable and the assembled die mounted onto a substrate does not have to be post cured, which is a benefit of the process. Of course, in other embodiments, the melting and reaction temperatures, as well as the target cure percentage may all be modified to meet the needs of a particular application.

[0023] Once the underfill material is cured, it should have specific thermal and mechanical properties to reduce the effects of thermal stresses without adversely affecting thermal performance of the flip chip. The cured underfill material should typically have

an elastic modulus in the range of 1 to 10 GPa. A mismatch between the coefficient of thermal expansion of the flip chip and the substrate on which the flip chip is attached exerts a shear stress on the solder joint. One function of the underfill is to provide additional (high strength) material in the plane of the solder joints across which the stresses can be distributed. Modulus values in the range 1 to 10 GPa as specified above allow the underfill to distribute these stresses without exceeding the fracture strength of the silicon.

[0024] It should be noted that although examples of 140% and 90% pre-cure underfill heights have been described, these percentages should in no way limit the scope of the invention. Rather either a larger or a smaller percentage may be used.

[0025] The applicants have found that for good solder joint reliability performance, the die 102 needs to be assembled with solder paste pre-printed on the board. During reflow, the paste will add to the original solder ball volume, effectively increasing the solder volume and height of the final interconnect. With coated packages, however, reflowing the parts over pre-printed solder paste was found to be unacceptable. As the underfill liquefies during reflow, the resin tends to entrain the solder paste powder, and move them away from the pads. As a result, the paste particles melt at different locations, and the desired standoff cannot be achieved. Preferable results were obtained when the solder paste is pre-printed on a board that was previously reflowed so that a layer of solder is present on the substrate pads prior to placing the devices. In manufacturing, the boards can be provided with pre-defined solder already applied to the substrate pads prior to moutning.

[0026] The underfill material 130 is self-fluxing, e.g., it already has a small amount of flux added to the epoxy base resin to eliminate solder oxide during reflow and allow proper wetting of the pads on the substrate . When the packages were placed on the

substrate pads to go directly into the reflow oven for board mounting, it was discovered that small perturbations (e.g., vibration from the conveyor belt, convection currents inside the oven, etc.) can displace the packages that had been carefully aligned. As a result, the packages may not be properly connected resulting in bad yield. For standard flip chip or array-based chip scale packages, this can be corrected mostly from the self alignment properties of the solder. With pre-applied underfill, however, self-alignment is much more restricted. Best results were achieved when a small amount of flux was dispensed on the substrate first, prior to the pick and place of the device. The sticky flux acts as a "glue" to hold down the package while being reflowed. As a result, higher assembly yields were obtained. The addition of the flux needs to be considered in the formulation of the self-fluxing underfill, since too much flux will affect the final properties of the underfill. (Flux is composed of low molecular weight materials, and will decrease the glass transition temperature of the underfill, affecting long term thermal cycling performance).

[0027] Furthermore with standard pick and place equipment, the vision system can rely on either the solder bumps or the outline of the package as fiducials for referencing. Accurate placement usually requires using the solder bumps. The die outline may be influenced by the quality of the dicing operation. Any chipping of the edge will affect the vision recognition, and impact the placement accuracy. The underfill coating may affect the vision system on some pick and place machines, resulting in poor placement accuracy. In some cases, this can be resolved by adjusting the lighting conditions (e.g., intensity, beam direction, etc.). In other cases, however, the coating will seem to mask the bumps, and as a result, the die outline will have to be used for pick and place of the package. Best results were achieved with underfill coatings that are level with the solder

bumps, since in this case, the outlines of the bumps can be identified. The thicker coatings result in good filleting, but will be affected by the quality of the vision system.

[0028] Figure 4 illustrates a flip chip die of the present invention mounted to a substrate such as a printed circuit board. Note the underfill material 130 forms fillets 132 after final curing.

[0029] Referring to Figure 5(a) and 5(b), a top view and a cross section view of wafer 100 according to another embodiment of the invention are shown. In this embodiment, a dam 140 is provided around the outer periphery of the wafer 100. The purpose of the dam is to prevent pre-cured underfill material from dripping or flowing off the wafer 100 after being dispensed onto the wafer. According to various embodiments, the height of the dam 140 can be varied to equal or exceed the thickness of the underfill material 130 applied to the wafer 100. The dam 140 can also be made of a variety of materials, for example a low viscosity cured epoxy.

[0030] Although only a few embodiments of the present invention have been described in detail, it should be understood that the present invention may be embodied in many other specific forms without departing from the spirit or scope of the invention. By way of example, in some embodiments, it may be desirable to mask the underfill material away from the saw streets as described in the parent application No. 09/359,214, which is incorporated herein by reference.

[0031] Therefore, the present examples are to be considered as illustrative and not restrictive, and the invention is not to be limited to the details given herein but may be modified within the scope of the appended claims.